ARPA-E's BEEST Program:
Ultra-High Energy, Low Cost Energy Storage for Ubiquitous Electric Vehicles

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Program Director, ARPA-E

March 1, 2011

Why do we care about the Electric Car?

THE OPPORTUNITY:

- Reduced Oil Imports
- Reduced Energy Related Emissions
- Lower & More Stable Fuel Cost

  (< $1.00/gallon of gasoline equivalent @ 10¢/kWh)

Why do we care about the Electric Car?

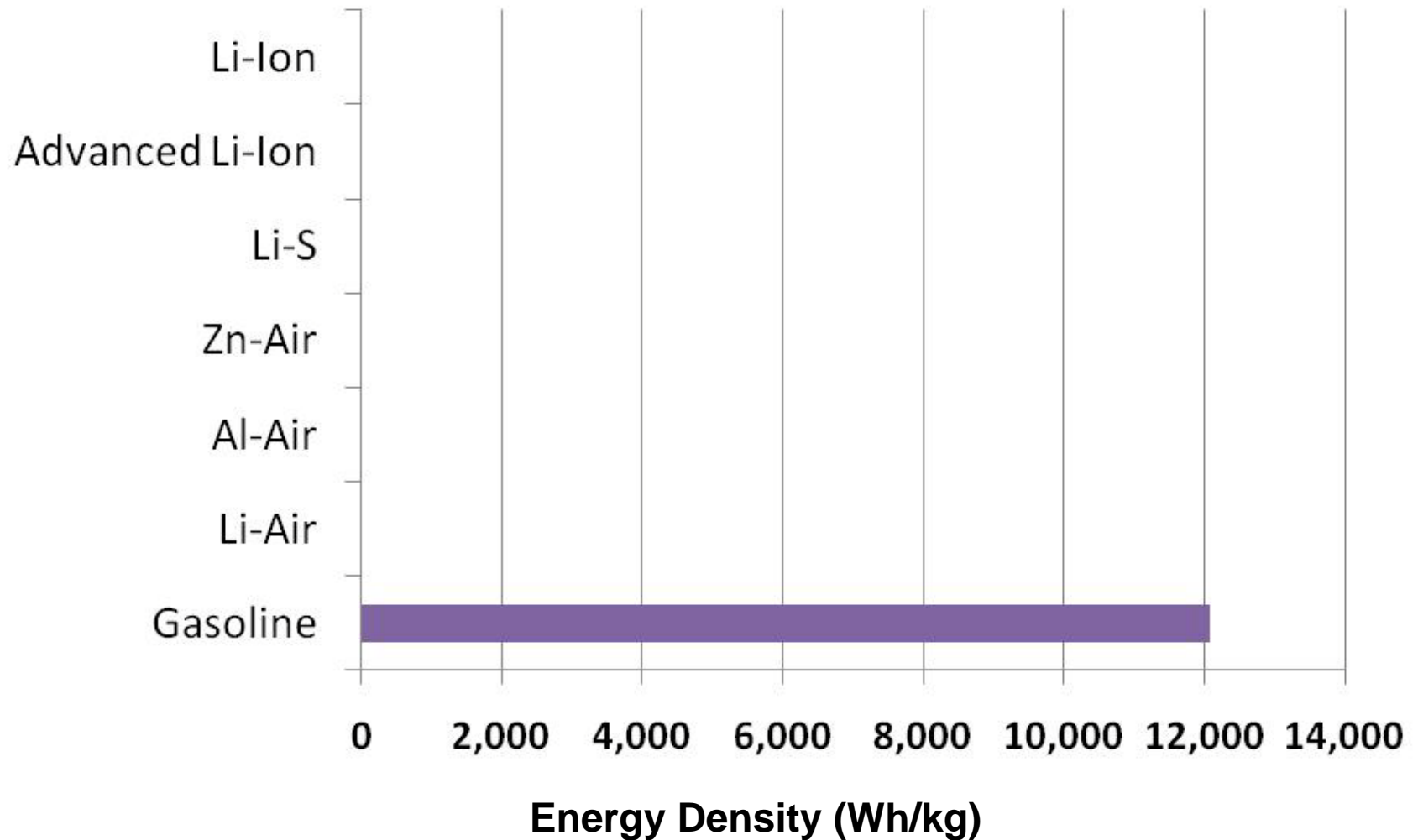## THE OPPORTUNITY:

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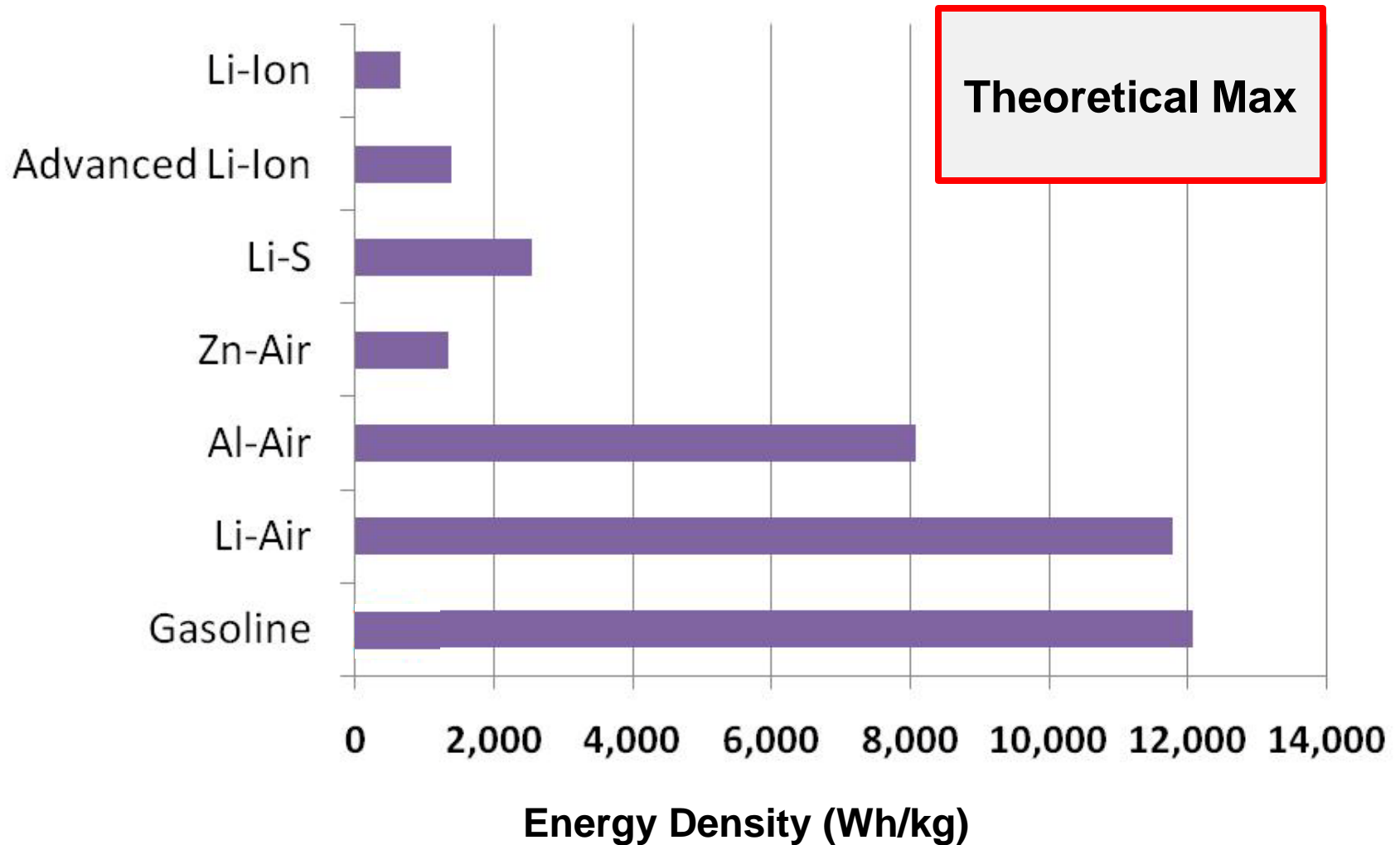 (< $1.00/gallon of gasoline equivalent @ 10¢/kWh)

THE CHALLENGE:

- Batteries…
  - Low Energy Density (Short Range)
  - High Cost

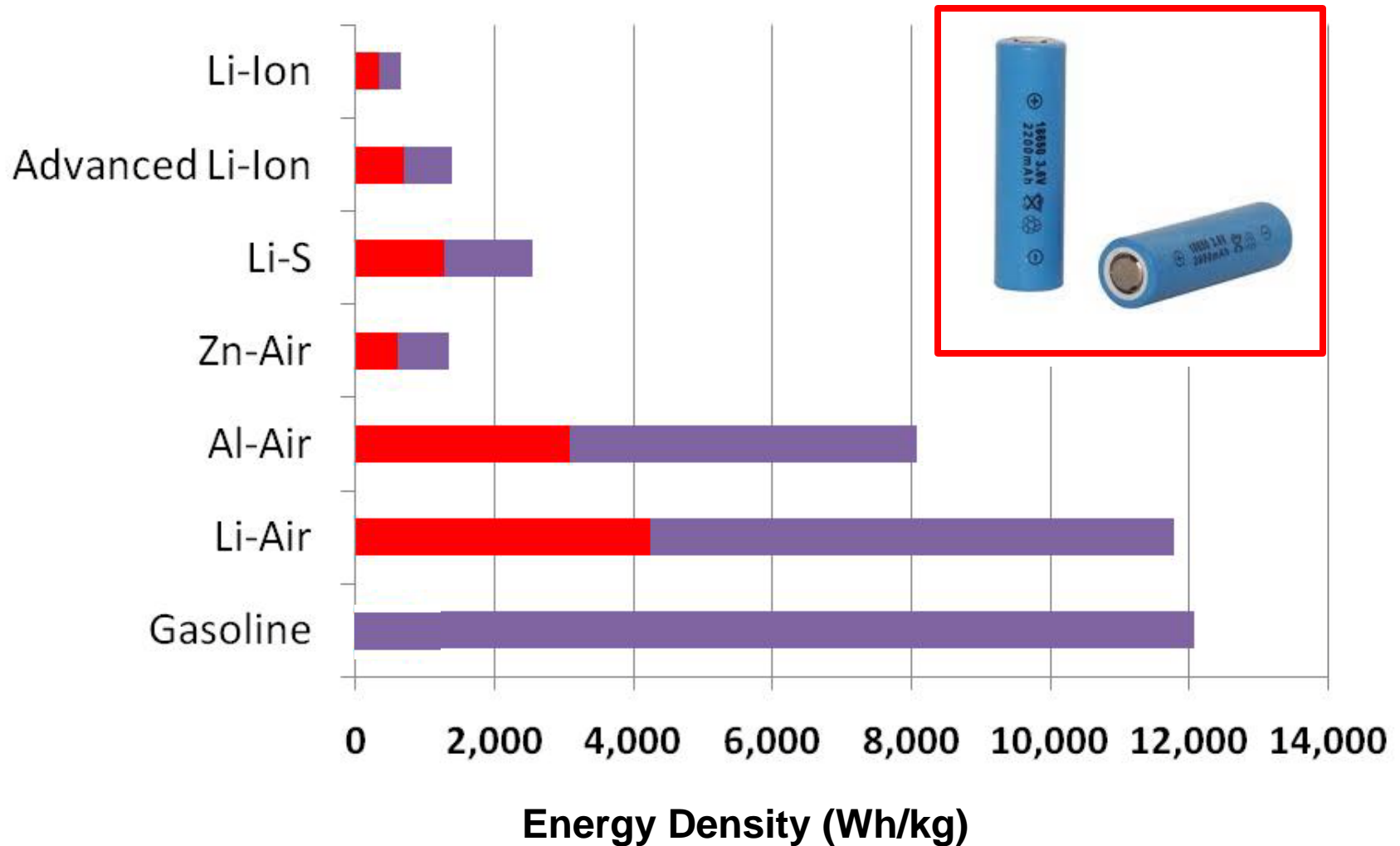# Do batteries have the potential to rival the energy density of gasoline powered vehicles on a <u>system level?</u>

Energy Density (Wh/kg)

Do batteries have the potential to rival the energy density of gasoline powered vehicles on a <u>system level?</u>

Theoretical Max

Chart — Energy Density (Wh/kg):
- Li-Ion: ~700
- Advanced Li-Ion: ~1,500
- Li-S: ~2,600
- Zn-Air: ~1,400
- Al-Air: ~8,100
- Li-Air: ~11,800
- Gasoline: ~12,000

Energy Density (Wh/kg)

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Energy Density (Wh/kg)

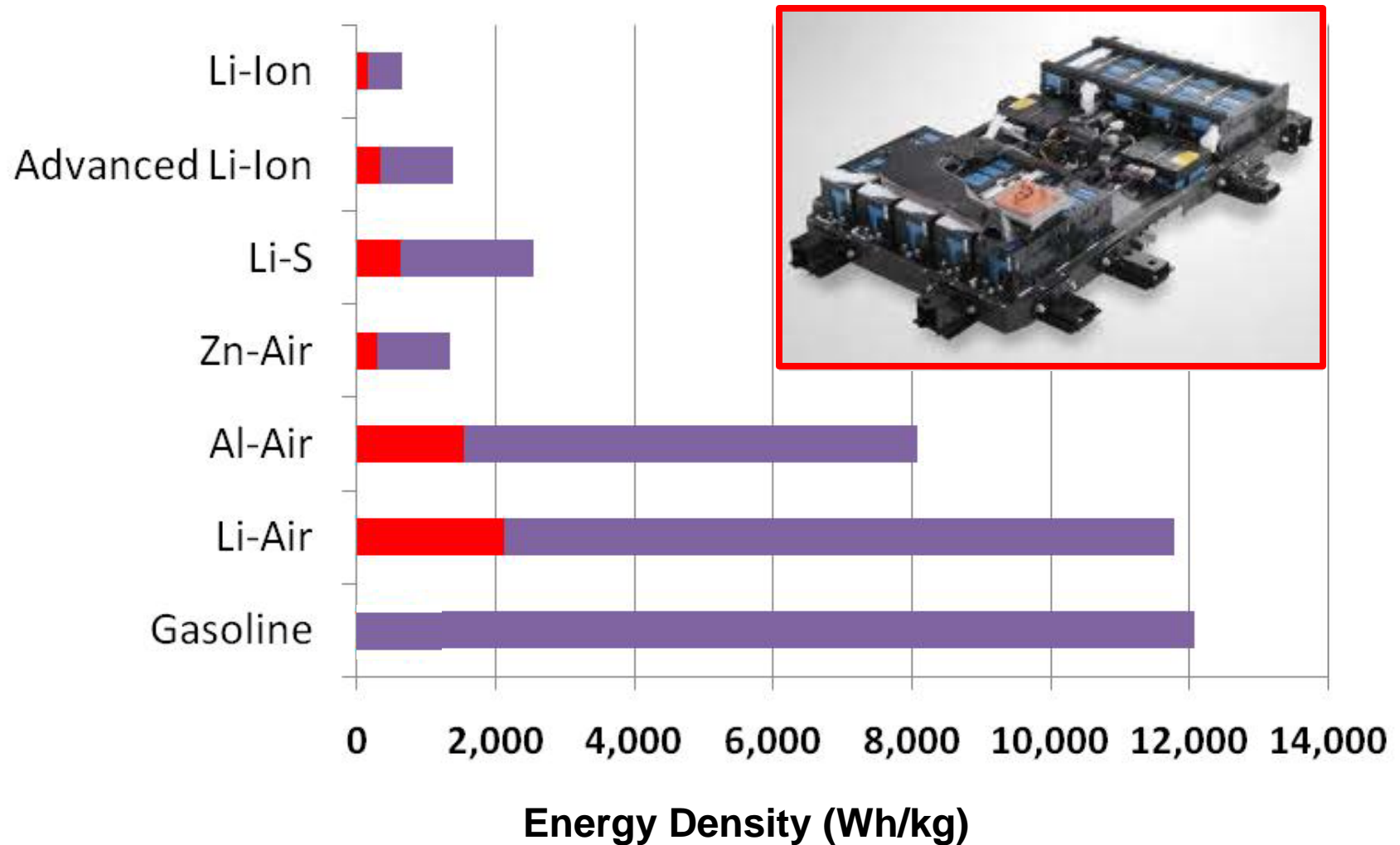# Do batteries have the potential to rival the energy density of gasoline powered vehicles on a <u>system level?</u>

Energy Density (Wh/kg)

Do batteries have the potential to rival the energy density of gasoline powered vehicles on a <u>system level?</u>

Energy Density (Wh/kg) — bar chart showing categories: Li-Ion, Advanced Li-Ion, Li-S, Zn-Air, Al-Air, Li-Air, Gasoline. X-axis: 0, 2,000, 4,000, 6,000, 8,000, 10,000, 12,000, 14,000

Energy Density (Wh/kg)
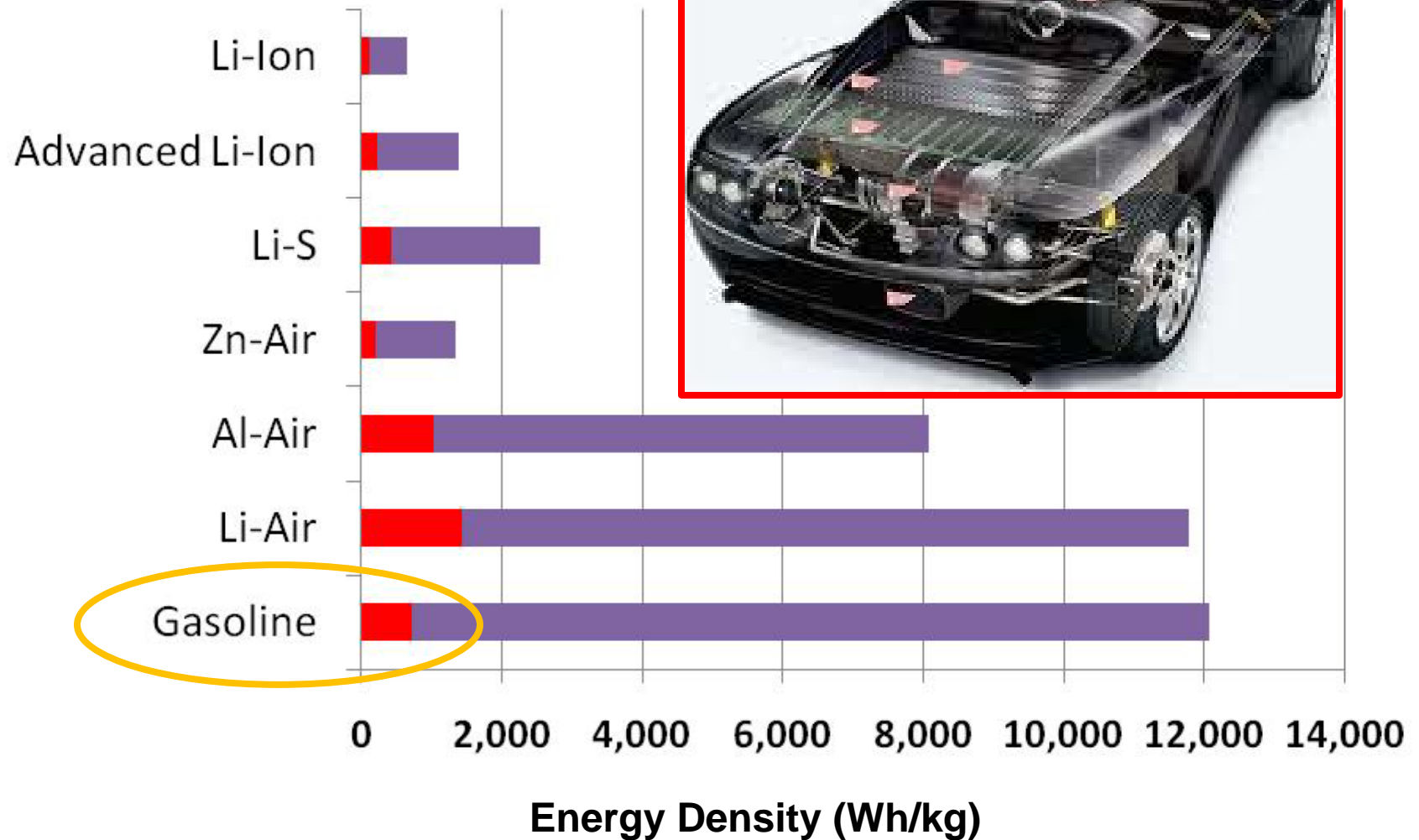
FACT: Batteries have the potential to rival the energy density of gasoline powered vehicles on a <u>system level</u>

Energy Density (Wh/kg)

Widespread Adoption of EV's Requires RANGE and COST Parity with Internal Combustion Engine Vehicles

> **COST:** ICE Cost Benchmark ~ **24¢/mile**
> **RANGE: 250+ mile range** needed to eliminate "range anxiety"

Widespread Adoption of EV's Requires RANGE and COST Parity with Internal Combustion Engine Vehicles

COST: ICE Cost Benchmark ~ **24¢/mile**
RANGE: 250+ mile range needed to eliminate "range anxiety"

Battery Pack Cost ($/kWh)	Discounted Vehicle Cost per Mile						
600	(0.22)	(0.27)	(0.32)	(0.37)	(0.42)	(0.47)	(0.52)
500	(0.21)	(0.25)	(0.29)	(0.34)	(0.38)	(0.42)	(0.46)
400	(0.20)	(0.24)	(0.27)	(0.30)	(0.34)	(0.37)	(0.40)
300	(0.19)	(0.22)	(0.24)	(0.27)	(0.29)	(0.32)	(0.34)
250	(0.19)	(0.21)	(0.23)	(0.25)	(0.27)	(0.29)	(0.32)
200	(0.19)	(0.20)	(0.22)	(0.24)	(0.25)	(0.27)	(0.29)
150	(0.18)	(0.19)	(0.21)	(0.22)	(0.23)	(0.24)	(0.26)
Vehicle Range (mi)	50	100	150	200	250	300	350
Pack Energy (kWh)	13	25	38	50	63	75	88

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Discounted Vehicle Cost per Mile

Now

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Large EV Penetration

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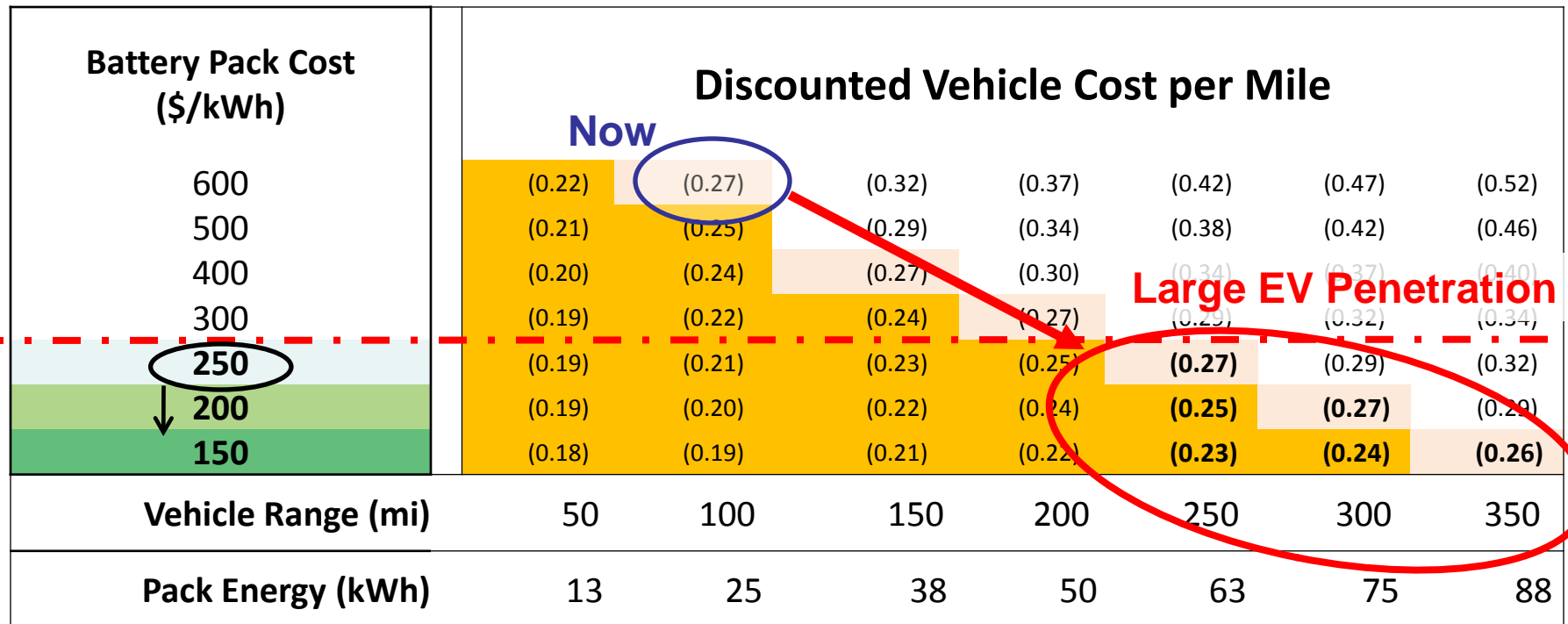**RANGE: 250+ mile range** needed to eliminate "range anxiety"

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Vehicle Range (mi)	50	100	150	200	**250**	**300**	**350**
Pack Energy (kWh)	13	25	38	50	63	75	88
Pack Energy Density (Wh/kg)	42	83	125	167	208 →	250	292

BEEST Program Targets: $50M/3 years

Current

100

**System Energy
(Wh/kg)**

1,000

**System Cost
($/kWh)**

BEEST Program Targets: $50M/3 years

	RANGE	**COST**
BEEST	**>200**	**<250**
	↑ 2x	↑ 4x
Current	**100**	**1,000**
	System Energy (Wh/kg)	**System Cost ($/kWh)**

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BEEST Program Targets: $50M/3 years

RANGE **COST**

BEEST

| >200 | <250 |

2x **4x**

Current

| 100 | 1,000 |

System Energy (Wh/kg) **System Cost ($/kWh)**
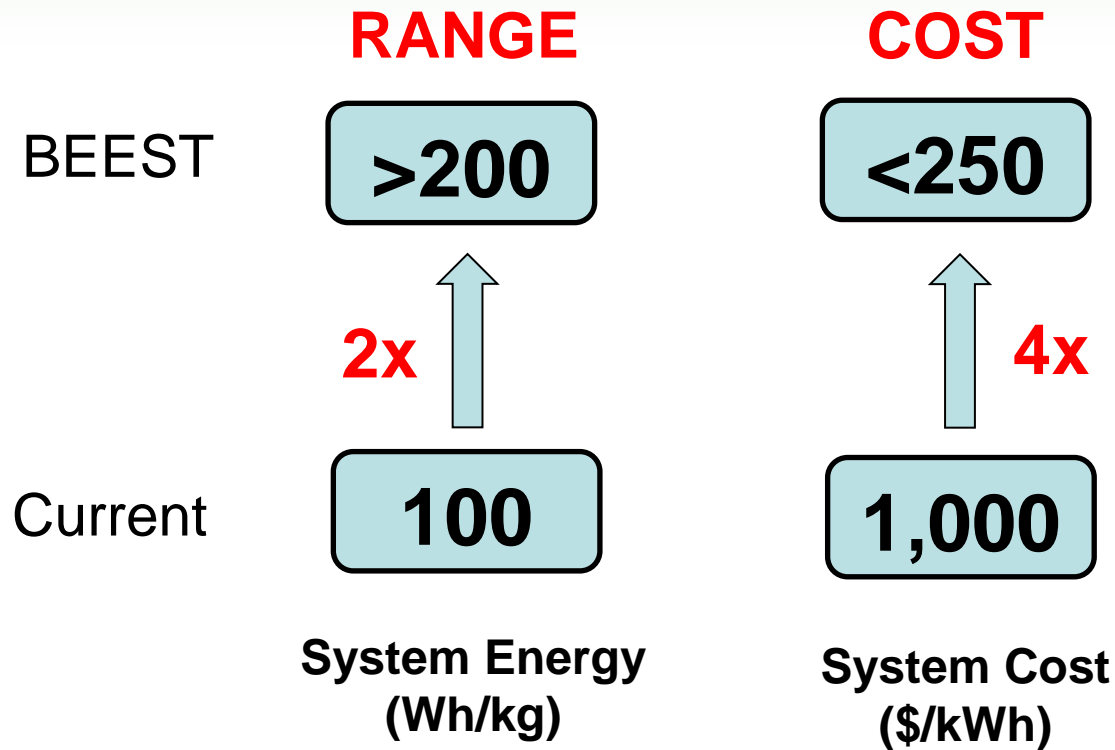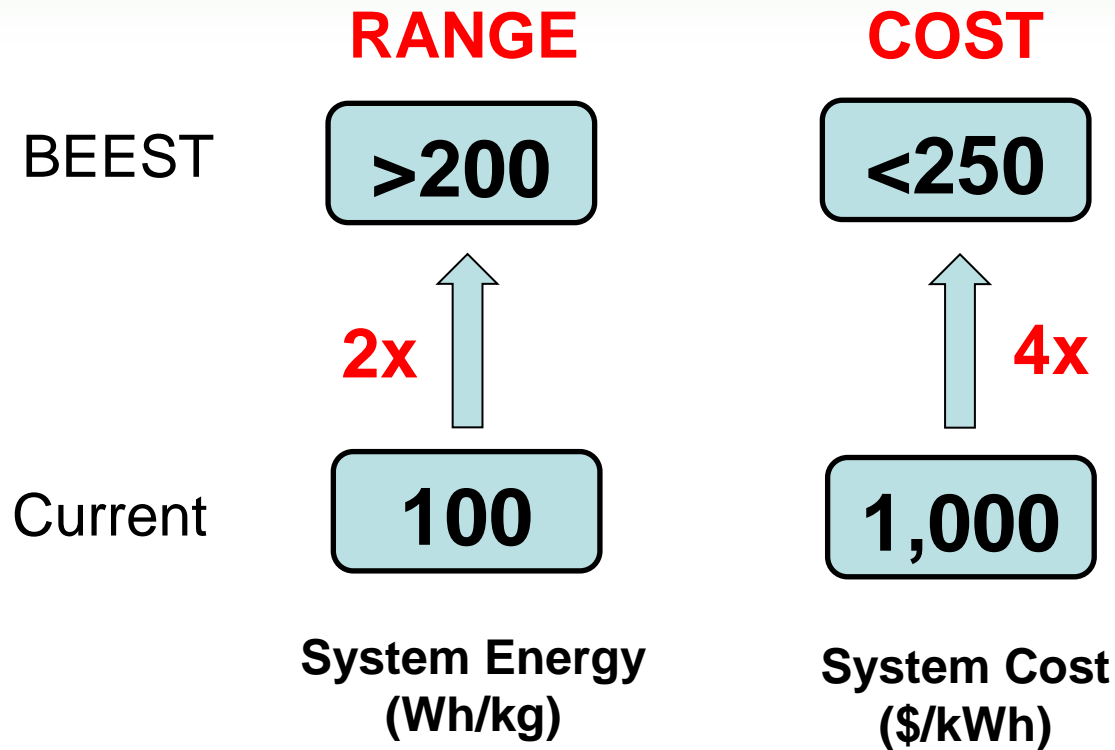
Secondary Metrics:
Power Density, Cycle Life, Round Trip Efficiency,
Self-Discharge, Safety, Etc.

BEEST Portfolio: Advanced Chemistries & Manufacturing

Upside

10 Advanced Prototyping Projects: $47.1M
4 Seedlings: $5.7M
TOTAL: **$52.8M/3 years**

System Targets:
200-400 Wh/kg
300-800 Wh/L

Recapping Inc.

STANFORD ENGINEERING

POLYPLUS
(Li-Air)

FastCAP SYSTEMS™
(Capacitive)

SION POWER
(Li-S)

24M
(Flow Batt)

FLUIDICENERGY
(Metal-Air)

MISSOURI S&T
(Li-Air)

Advanced Lithium

Pellion Technologies Inc.
(Mg-Ion)

REVOLT TECHNOLOGY
(Zn-Air)

PLANAR ENERGY
(Solid State Li)

envia SYSTEMS
(Si anode)

Ultra-High Energy

APPLIED MATERIALS.
(Li Ion Mfg)

Inorganic Specialists, Inc.
(Si anode)

Infrastructure Compatible High Energy Materials

"Time to Market"

BEEST Program – Project Spotlights

- Envia Systems – Dr. Sujeet Kumar, CTO

- Planar Energy Devices – Scott Faris, CEO

- 24M Technologies – Dr. Yet-Ming Chiang, Chief Scientist

- PolyPlus Battery Company – Dr. Steve Visco, CTO